Mira Variables at PTI: Size/Shape with Phase and Limb Darkening

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Science Objectives and Summary

The study of Mira variables has a long history in astronomy, starting with the discovery of Mira (omicron Ceti) as a variable star by David Fabricius in 1596. Miras themselves belong to the class of M giant and supergiant stars which are Asymptotic Giant Branch (AGB) stars. Because these stars are large, bright, cool and pulsating, they are of great interest to many subfields of astrophysics. Pulsation, in particular, is one of the few phenomena in astrophysics that changes on contemporary timescales and thus can be monitored in real time. Miras also produce many molecules and solid-state products in their cool, extended atmospheres which they throw off through a poorly understood process of mass-loss. The products which they return to the galaxy are of interest in the search for extra-solar planets as the building blocks for these bodies. Despite a lengthy history of study, there are still many unanswered questions with respect to these stars. Three relevant areas where we believe PTI can make significant contributions in the study of mira variables this observing season are:

- Measuring changes in the apparent diameter of a group of miras with respect to phase.
- Quantifying the apparent diameter of these miras at H and K (dual-band mode) to determine the extent of limb darkening.
- Identifying possible asymmetries in the photospheres of these sources.

The importance of each of these contributions is discussed in more detail below.

Diameter Changes with Respect to Phase The unambiguous determination of the diameters of mira variables is highly important toward answering the question of whether mira variables are fundamental or first overtone pulsators. Previous IR interferometric studies of miras were inconclusive with respect to pulsation mode (van Belle et al, 1996 and 1997) due to sparse information on distance scales to these sources. The pulsation-mass-radius relationship (PMR) for determining the pulsational constant states:

$$Q = P(M/M_{\odot})^{1/2}(R/R_{\odot})^{-3/2}$$

where Q is the pulsational constant, P is the period in days, and all other variables have their usual meaning. The masses of miras are in a very narrow range of 0.8-2.0 $M_{\odot}$, leaving the radius as the most ambiguous quantity. It has been shown that the radius of a mira can vary by 35% throughout its cycle (van Belle et al., 1996; Burns et al., 1997). The power of monitoring miras with PTI will be in our development of a statistical database measured in the angular size range at which PTI is most sensitive to these types of changes. Determination of Q will allow complete modeling of these stars at the level to render them standard candles. As standard candles, they are intrinsically much brighter than Cepheids and RR Lyrae typically used, do not suffer the same extinction problems in the near and mid-IR and will allow much better distance determination to distant galaxies. Furthermore, determination of the diameter of miras will allow us to more precisely determine the effective temperatures of these stars:

$$T_{eff} = 2341(F_{bol}/\phi^2)^{1/4}$$

where F_{bol} is in 10^{-8} ergs cm^{-2} s^{-1} and ϕ is in milliarcseconds. It is well-known that a mira can change by five or more visual magnitudes during one period while only changing one magnitude in the infrared. This, along with infrared scatter in the photosphere and abundant absorption features, has made good determination of the temperatures of miras very difficult. With PTI, we should be able to get a much clearer idea of the actual temperature excursions in miras, allowing yet another step toward establishing these sources as standard candles. Finally, there is some evidence that similarly classed pulsating and non-pulsating giants and supergiants exhibit very different effective temperatures (Ridgway 1991; Dyck et al., 1996; van Belle et al., 1996) Clarifying whether or not this is the case will aid greatly in modeling of the photospheres, mass-loss processes and convection that occur in these sources.

Dual-band Limb Darkening Studies Limb-darkening parameters are usually arrived at through modeling of a spherical stellar source (Scholz and Takeda, 1987; Bessell et al. 1989). Normal giants and supergiants with fairly compact photospheres show smooth limb-darkening curves. Although these curves may not always be well-approximated by linear-laws, they are nevertheless relatively well-behaved. The case is not so clear for mira variables (Scholz and Takeda, 1987; Haniff et al., 1995). Through use of the low-resolution spectroscopic capabilities of the PTI dual-band mode, it may be possible to constrain these laws, allowing limb-darkening models to be developed for these sources which may be different than models for their non-varying counterparts.

Assymetries in the Photospheres While departure from spherical symmetry is well-documented for the extended dust regions of AGB and post-AGB stars, very few studies have been undertaken to quantify the departure of a star itself from spherical symmetry (Karovska et al, 1991; Haniff et al, 1992; Quirrenbach et al., 1992). Besides being a general curiosity, and a new difficulty for modelers, the implications of non-spherical symmetry in these sources suggest questions about their mass-loss properties (clumpy vs. steady flows) and modes of pulsation (non-radial superimposed on radial modes). It is important to determine whether the majority of these cool, bloated sources are non-spherically symmetric and to what extent. In this context, it may be interesting to follow a few sources carefully throughout their cyclic variation to determine whether any non-sphericity is random or tied to the pulsational cycle. For example, there is some evidence for a change in the positional angle (PA) of the semi-major axis of a non-spherical stellar distribution of Mira using the Mark III interferometer, which was only followed through a small portion of the pulsational cycle, making it difficult to determine whether changes in the PA were random, or tied to the pulsation (Quirrenbach et al., 1992). Determining whether a non-sphericity is in fact the result of non-radial pulsation or clumpy mass-loss could open new doors of understanding for this field of stellar evolution.

The Sample: Requirements for PTI

We have chosen a sample of 26 mira variables with visual magnitudes of at least 8 at maximum, and apparent diameters (determined from models for M giants) between 1 and 5 milliarcseconds. These sources were chosen specifically to be within PTI's declination limits and all of them have contemporaneous visual light curves from the AAVSO, which will be instrumental in unambiguously determining the period, epoch, and best time to acquire these sources. The visual light curves also give indications of which sources may be pulsating with double-periods, semi-regular periods, double-shocked atmospheres (hump on the ascending light slope) or proceeding towards a thermal pulse (steadily shortening pulsational cycles). Also, because these sources are relatively bright, we expect to be able to identify them in the Hipparcos and Tycho catalogues, in order to have reasonable distance scales for luminosity calculations and reddening corrections. Since many of these sources will be much less than 10th magnitude in the visual during some part of their cycles, we do not expect to monitor all sources through their entire period; most will only be monitored near maximum light. The use of dual-band mode, and alternate baselines to get better u-v coverage, will cast this program as one of the more time-intensive ones for PTI this season, at the same time demonstrating the full-potential and strength of infrared interferometry.

Observing Strategy

Each of the three subprograms on mira variables will be executed in a slightly different fashion. 1) Diameter changes with respect to phase will be monitored for most sources (spread evenly across RA) for 40-60 days near maximum light (10-20% of their cycles). This means at any given time from one to three (of 22) miras will be visible and attainable from PTI. Another four miras in the total sample are brighter than 6.5 visual magnitudes at maximum light, making these four the only candidates which might be monitored throughout their light cycles. 2) Limb-darkening studies can initially be undertaken at one phase point in the light cycles of these miras. We would like to attempt, once dual-band observations come on line later this year, to image four to seven bright miras in our sample for a few nights. This short run could be included with a limb-darkening study of non-varying giant stars. Together, this study will make a good basis sample for comparison of limb-darkening for some small-number statistics. If there prove to be interesting limb-darkening effects in this sample, we may request follow-up time to get more observations on these same sources at slightly different phase to determine whether limb-darkening is phase dependent. 3) Measuring departures from spherical symmetry could be attempted as a regular part of measuring diameter changes with phase, provided changing baselines is not a time-consuming process. Alternatively, baselines could be traded off during the week, and measurements taken using different baselines on consecutive nights. Based on these strategies, we would provide a list of which miras in our sample are available for PTI at any given time, along with preferred reference calibrators for these sources, and request to have these sources injected as a regular observing program on any given night. As we anticipate only a few miras being visible each night, we expect to spend about 6 to 7 hours a week on this program (assuming 3 sources plus calibrators, 3 nights each week). A concentrated program of limb-darkening measurements could take place later in the season once the dual-star module is operational, utilizing the full resources of PTI for 3 nights.

Collaboration

While all of the PTI collaboration are invited to assist in this project, Gerard, Ben and myself are the main conspirators. We expect that Gerard and I will supply the expertise for modeling the mira variables, while Ben's expertise with PTI will be most necessary toward implementing all the described modes of observation.

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